HEO Multimission Navigation Concept

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As part of the Network Consolidation Program, the 26-meter Tracking and Communication Subnet was transferred to JPL. Along with this transfer JPL assumed responsibility for tracking and navigation support for Earth orbiter missions normally tracked by the 26-meter sites. The High Earth Orbiter (HEO) Multimission Navigation Facility was formed as a component of the DSN Tracking System for the purpose of supporting Earth orbiter missions and certain classes of deep space missions. This facility has been implemented on a dedicated VAX 11/780 minicomputer within the Network Operations Control Center (NOCC). The primary function of the system is to process radio metric data and estimate the orbit of a spacecraft in near-Earth or deep space environment. The system is capable of processing radio metric data in near-real time and providing the quick turnaround required for Earth orbiter operations. It is also capable of generating precision spacecraft ephemeris for use by the NOCC Support Subsystem and external agencies. This article discusses the implementation and functional operation of the Multimission Navigation Subsystem and describes the support that has been provided for an array of missions.

I. Introduction

As part of the Network Consolidation Program, the 26-meter Ground Spaceflight Tracking and Data Network (GSTDN) was transferred from Goddard Space Flight Center (GSFC) to JPL as an element of the MARK IVA DSN. Along with this transfer, JPL assumed responsibility for tracking and navigation for Earth orbiter missions normally tracked by the GSTDN sites. This includes all high Earth orbiter missions and Earth orbiters which are not compatible with the Tracking and Data Relay Satellite System (TDRSS). The High Earth Orbiter (HEO) Multimission Navigation Facility was formed as a component of the DSN Tracking System for the explicit purpose of supporting Earth orbiter missions and certain classes of deep space missions. The latter typically includes non-JPL deep space missions that are tracked by the DSN.

The development of this facility was influenced by a DSN Advanced Systems program in which a limited prototype navigation system was developed for a VAX 11/780 minicomputer. This research effort demonstrated the feasibility of providing low cost and efficient multimission navigation support using a dedicated minicomputer. It also provided the opportunity to introduce new technical capabilities to enhance the navigation operations process. This has included automatic loading of data files, electronic transfer of files, interactive graphic display and data editing, and the capability of providing the quick turnaround needed for the near-real-time navigation support for critical Earth orbiter mission events.

Based on the results of the Advanced Systems demonstration, the HEO multimission capability (NAV) was implemented within the Network Operations Control Center (NOCC) using the backup Network Support Controller VAX 11/780 (NSC1). The primary VAX 11/780 (NSC2) is used for the generation and transmission of station predicts, the generation of scheduling information, and the preparation of mission sequence of events. Data are transferred between NSC1 and NSC2 via the DECNET. In the event of a failure of either machine, the Advanced Systems VAX 11/780 serves as backup to NAV.

The implementation of the NAV subsystem was scheduled to meet August 1984 AMPTE (Active Magnetospheric Particle Tracer Explorers) mission requirements, which was the first high Earth orbiter mission supported by the MARK IVA system. The early completion of the deep space development phase enabled the system to be operational for the ICE (International Comet Explorer) mission support starting in March 1984. To date, the NAV facility has supported 13 missions for 7 different space agencies. This support has included navigation for launch, Earth orbiter, geosynchronous orbit transfer, deep space cruise, and planetary and comet encounter phases.

II. Functional Description

Figure 1 shows the NAV subsystem functional interfaces and data flow. The HEO facility is responsible for performing the following functions:

(1) Prelaunch navigation systems analysis. This includes defining tracking data requirements and establishing expected orbit determination accuracies.

(2) Radio metric data analysis.

(3) Operational orbit determination.

(4) Generation of precision spacecraft ephemerides for use by the NOCC Support Subsystem (NSS) and for transmission to external agencies.

(5) Spacecraft maneuver analysis.

(6) Generation of DSN navigation deliverables for flight projects and external agencies. These include processed tracking data files, spacecraft state vectors and spacecraft ephemerides, and other trajectory-related products.

As shown in Fig. 1, the NAV system receives the following data from external sources:

(1) Radio metric data transferred from the DSN subnets via the Ground Communication Facility (GCF) Digital Communication Subsystem.

(2) Correlated VLBI data from the NOCC Radio Science/VLBI Processor Subsystem (NRV).

(3) Timing, polar motion, and media calibrations from the Tracking and Systems Analytical Calibrations Group (TSAC).

(4) Spacecraft state vectors generated by external agencies, typically transferred via the high-speed data lines in an Intercenter Vector format (ICV).

NAV delivers the following products for external transmission:

(1) Spacecraft ephemeris files for antenna pointing and frequency predictions.

(2) Validated radio metric data in the form of an Orbit Data File (ODF) for transfer to external agencies.

(3) State vector estimates generated by the NAV subsystem in the form of an ICV.

(4) Project-related trajectory products generated from the spacecraft ephemeris.

III. NAV Subsystem Organization

The NAV subsystem consists of the Radio Metric Data Conditioning (RMDC), Orbit Determination (OD), and Trajectory Analysis (TRAJ) subsystems. Figure 2 shows the organization of the NAV subsystem.

A. NAV Subsystem Characteristics

1. Radio metric data conditioning subsystem. The primary function of the RMDC is to receive the radio metric data and prepare an orbit data file for use by either JPL NAV or for transmission to external agencies. The RMDC receives radio metric data consisting of doppler, range, angles, VLBI, and other ancillary information (e.g., calibrations, reference frequencies, validation codes, mode indicators) required to process these data. The data are transmitted in real-time via an electrical interface and automatically loaded onto NSC1. The data are edited – this consists of reordering the incoming data, identifying invalid data, deleting unwanted data types, compressing doppler and narrowband VLBI, and applying calibrations based on station and spacecraft characteristics. The primary output is a validated tracking data file (ODF) in a format suitable for use by NAV or in a format for transmission via the high-speed data lines to external agencies. During critical periods, the RMDC must be capable of processing a one-hour span of data within 5 minutes; for non-critical periods RMDC must edit a one-week data file within 60 minutes.

2. Orbit determination subsystem (OD). The primary function of the orbit determination segment is to estimate the spacecraft state along with other relevant parameters using the processed ODF provided by the RMDC. The OD component consists primarily of the Orbit Determination Program (ODP), which includes a complete set of algorithms necessary to model the motion of a planetary orbiter or a deep space probe and to model the radio metric observations. The program is capable of estimating the spacecraft state, spacecraft dynamic parameters (i.e., maneuvers, solar pressure constants, gas leaks), astrodynamic and geophysical parameters, and observational parameters. It has the capability of processing the data using either a gaussian least squares filter or a batch sequential filter and smoother algorithm which accounts for the effects of correlated process noise. Estimates and their statistics can be time-mapped and displayed in a variety of coordinate systems with respect to different reference frames. The ODP also displays the pre- and post-fit data residuals and provides an assessment of the quality of the radio metric data.

3. **Trajectory analysis subsystem.** The primary function of the Trajectory Analysis Segment is to generate a precise spacecraft ephemeris using either an estimated state provided by the ODP or a state vector estimate transmitted by an external agency. This spacecraft ephemeris is used as the source for the trajectory files and Probe Ephemeris Tapes (PET) transmitted to the NOCC Support Subsystem (NSS) for station antenna pointing and frequency predicts. It is also used to generate specific trajectory-related data required by the project, and to generate state vectors in the form of an Intercenter Vector (ICV) for transmission via the high-speed data lines to external agencies. TRAJ will also accept as input an ICV transmitted by an external source and generate a spacecraft ephemeris based on this state.

B. Auxiliary Capabilities

In addition to the primary functions, the NAV system includes the following capabilities:

(1) Simulation of radio metric data for use in covariance analysis studies, operations readiness testing and general operations test, and training activities. This capability has been used to provide external users with simulated data for compatibility testing.

(2) Generation of station view periods.

(3) Preparation of NAV-related mission support timelines and sequence of events.

(4) Procedures to monitor the consistency of orbit estimates.

(5) Procedures for the near-real-time assessment of maneuvers and determination of spacecraft spin rates.

C. Software Implementation

The HEO NAV subsystem consists principally of software modules inherited from the UNIVAC-based navigation system. The UNIVAC version of the software was converted to be compatible with the VAX. Additional models were added to meet the specific NAV mission requirements. These included Earth atmospheric models, an Earth tide model, and the ability to process GSTDN range data. The Earth orbiter navigation phase of the software was tested and certified by comparing results with those independently determined by the GSFC Orbit Determination Program. The deep space modules were certified using the test case library that had been established to certify the UNIVAC version.

IV. Mission Set

The multimission NAV system has provided navigation for launch, Earth orbiter, deep space cruise, planetary flyby, and comet encounter mission phases. All missions that encountered the comet Halley in March 1986 were supported by the NAV subsystem. The missions that have been supported by this facility from FY84 to mid-FY86 and the level of support are described in Table 1. Future missions (mid-FY86 through FY88) are given in Table 2. This future mission set consists primarily of geosynchronous orbiter missions which will require HEO NAV support during the geosynchronous orbit transfer phase.

Table 1. Missions supported: 1984 — 1986

Mission	Agency	Significant Dates	NAV Role	Interface
International Comet Explorer (ICE)	GSFC	Launched as ISEE-3: 08/12/78 Renamed ICE: 12/22/83 Encounter: 09/11/85	Orbit determination in parallel with GSFC during lunar swingby Dec 83 and then prime during interplanetary cruise, comet Giacobini-Zinner encounter and for subsequent solar wind observations upstream of comet Halley during 1986.	*From JPL*: Intercenter State Vectors (ICV) initially via Telex. Now via high-speed data line (HSDL) electrical interference.
Active Magnetospheric Particle Explorer (AMPTE)/ Charge Composition Explorer (CCE)	GSFC	Launched: 08/16/84 Projected Lifetime: 4 yr	Provide OD support and generate trajectory products throughout mission lifetime.	*From JPL*: ICV (TRK 2-17) sent over HSDLs. *From JPL*: Flight path information sent via tape to Applied Physics Lab (TRK 2-22).
AMPTE Ion Release Module (IRM)	German Space Operations Center (GSOC)	Launched: 08/16/84 Projected Lifetime: 1 yr	Provide OD solutions during first 10 days after launch for compatibility testing with GSOC. Generate and transmit orbit data files for DSN tracking data acquired during periods of cannister release. GSOC will provide ICV for Predix generation.	*From JPL*: ICV (TRK 2-17) for first 10 days for solution comparison via HSDL. *From GSOC*: ICV (TRK 2-17) for data acquisition during cannister release via HSDL. *From JPL*: Orbit data files (TRK 2-18) via HSDL.
(MST5) Sakigake	Institute of Space and Astronautical Science, Japan (ISAS)	Launched: 01/07/85 Encounter: 03/11/86	Assist ISAS with validation of their OD software by providing Voyager tracking data for testing, comparing OD solutions and providing analysis and software consulting service; includes plans for workshop at JPL. Provide OD solutions and tracking data for the first 10 days after launch. Provide OD consulting for 6 months following launch.	*From JPL*: ICV via telex. *From JPL*: ODF tape (TRK 2-18) covering 10-day period.

Table 1 (contd)

Mission	Agency	Significant Dates	NAV Role	Interface
VEGA Venus Balloon Experiment	Centre National D'Etudes Spatiales (CNES) Space Research Institute (IKI), USSR	Launched VEGA1: 12/15/84 Encounter: 06/11/85 Launched VEGA2: 12/21/84 Encounter: 06/15/85	Determine VEGAorbits during heliocentric cruise and Venus flyby phases using L-band (1.667 GHz) delta DOR, one-way doppler combined with geocentric information provided by IKI. Provide processed delta DOR observations to support IKI post-Venus flyby maneuver.	*From CNES*: VEGA orbital state estimates and spacecraft dynamic parameters. *From CNES*: L-band (1.667 GHz) oscillator characteristics. *From JPL*: VLBI-based OD solutions. *From JPL*: Processed delta DOR observations.
Giotto	European Space Agency (ESA)	Launched: 07/02/85 Encounter: 03/14/86	Assist ESA with OD software development and validation by comparing solutions using test cases based on Voyager tracking data; conduct joint workshops at JPL and ESOC. Provide orbit data files during cruise and encounter phases. Determine flight path and compare solutions for designated rehearsal periods during cruise.	*From JPL*: ODF files (TRK 2-18) via HSDL. *From ESOC*: ICV (TRK 2-17) via HSDL. *From JPL*: ICV (TRK 2-17) via HSDL. *From ESOC*: State vector solutions, covariances and dynamic parameter estimates via Telex.
Pathfinder	European Space Agency (ESA) Space Research Institute (IKI), USSR	Launched VEGA1: 12/15/84 Encounter: 03/06/86 Launched VEGA2: 12/21/84 Encounter: 03/09/86	Provide VLBI-determined orbit solutions for the heliocentric cruise phase (post-Venus encounter) and the comet Halley encounter phase. Provide processed delta DOR observations.	*From ESOC*: Orbit state vectors; transponder characteristics. *From JPL*: VLBI-determined orbit estimates. *From JPL*: Processed delta DOR observations.
(Planet-A) Suisei	ISAS	Launched: 08/18/85 Encounter: 03/08/86	Provide OD solutions to support USUDA station predicts and tracking data covering the first 4 mo following launch. Provide consulting service for 6-mo period after launch.	*From JPL*: ICV via Telex. *From JPL*: ODF tape (TRK 2-18) for first 10 days.

Table 1 (contd)

Mission	Agency	Significant Dates	NAV Role	Interface
Broadcast Satellite-2B (BS-2B)	National Space Development Agency, Japan (NASDA)	Launched: 02/12/86 Support Period: Launch to L+30 days	Orbit determination during orbit transfer phase from L to L+(Apogee Kick Motor Firing) AKM + 30h with solutions at L+6.5 h, L+10 h, L+29 h, L+61 h; contingency support to L+1 mo; covariance studies to assess the performance of tracking from a single site for L to L+5 h.	*From NASDA*: ICV (TRK 2-17) via HSDL. *From JPL*: ICV (TRK 2-17) via HSDL. *From JPL*: ODF files (TRK 2-20) via HSDL GSTDN data only.
Extended Missions (ISEE-1, ISEE-2, DE-1, NIMBUS)	GSFC		Provide antenna predicts for 26-m subnet using ICV provided by GSFC.	ICV from GSFC.

Table 2. Future missions: 1986 — 1988

Mission	Agency	Date
GOES-H	NASA	10/86
TELECOM-1C	CNES	12/86
TV-SAT	GSOC	03/87
TDF-1	CNES	07/87
ETS-V	NASDA	08/87
TELEX-X	CNES	12/87
DFS-1	GSOC	02/88
CS-3A	NASDA	02/88
TV-SAT2	GSOC	05/88
TDF-2	CNES	07/88
CS-3B	NASDA	08/88

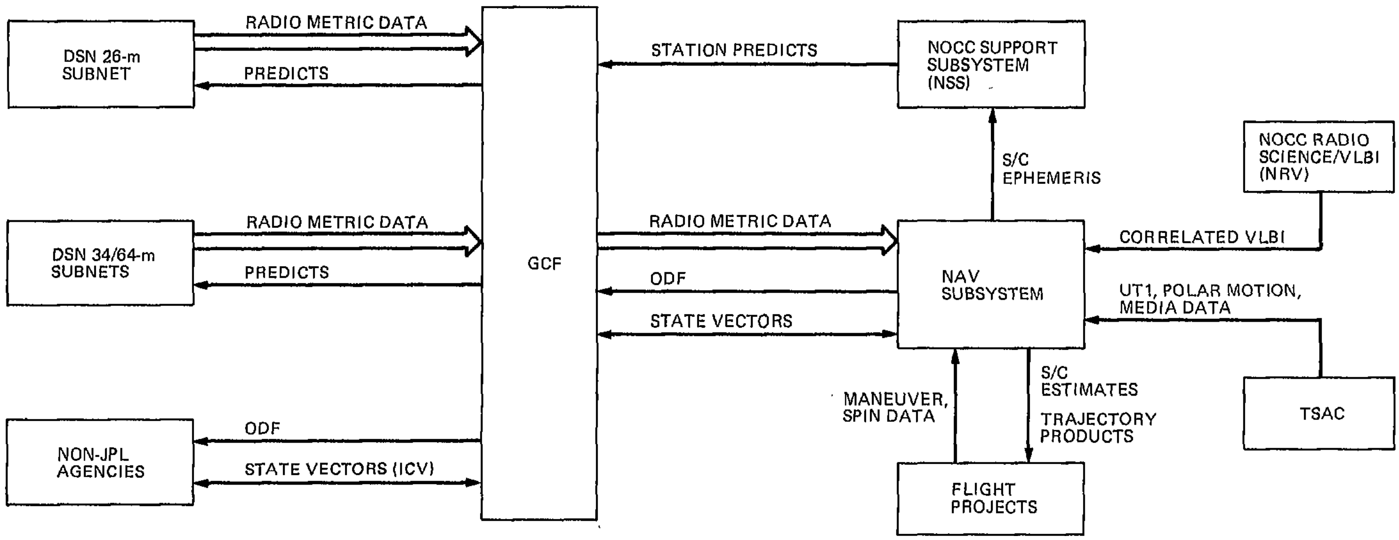

Fig. 1. NOCC Navigation Subsystem functional data flow

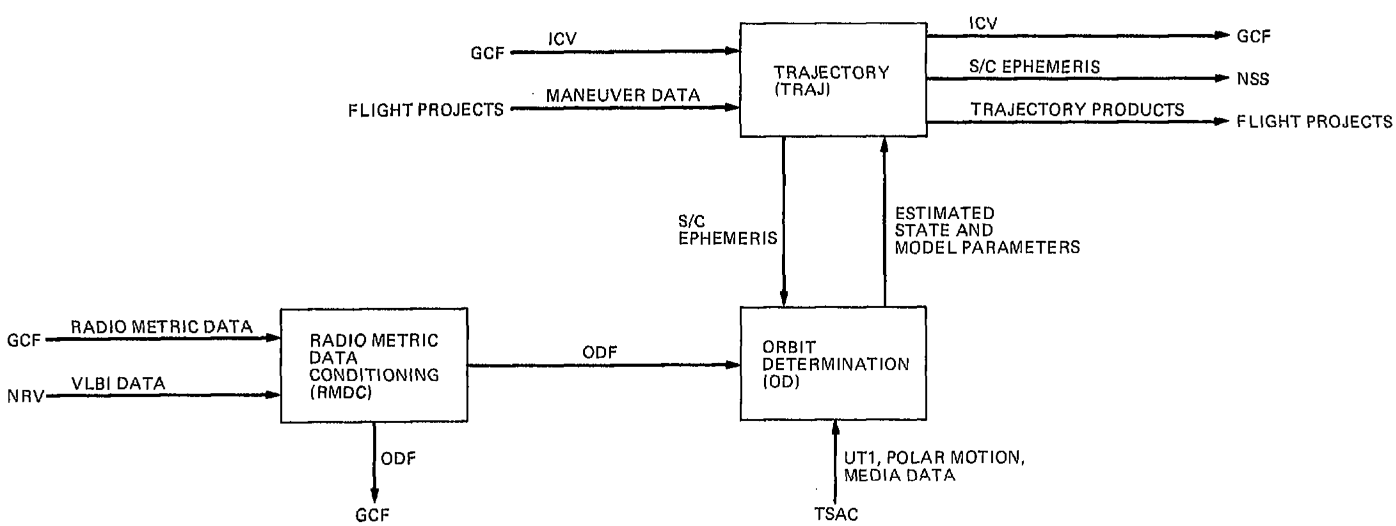

Fig. 2. NOCC Navigation Subsystem organization